TECHNICAL NOTES

U.S. Department of Agriculture **Natural Resources Conservation Service**

TN – Agronomy - CA - 70 July, 2011

Evaluation of an On-Farm Sampling Method for Estimating Soil Carbon Levels on Rangeland Sites in the Sacramento Valley, CA

Background

The idea of promoting agricultural practices that may reduce atmospheric CO^2 (CAST 2000; USDA 2000) has attracted the interest of national leaders, scientists, agencies at all levels, and a plenitude of conservation organizations and business ventures. It has also caught the attention of farmers and ranchers, for whom such efforts may create new opportunities for environmental stewardship and revenue generation, and pathways to alternative production practices.

In California, some owners of the state's nearly 20 million acres of private rangelands, have been closely following the development of carbon credit markets. Reasons for this include, (1) a desire to diversify ranch revenue-generating opportunities, (2) additional basis for branding as 'green' other products from the ranch, and (3) an anticipation that revenues and/or government aid tied to carbon sequestration might leverage desired but sometimes difficult and risky conservation projects, such as conversion of annual grass pastures to perennial grass pastures.

In the last case, not a few ranchers envision circumstances whereby such replacement of annual grasses with perennials could gain them greater forage production and longer growing seasons (Menke, 1992), and, as has sometimes been suggested, sequester more soil carbon to boot. The extent to which such expectations could be realized in practice has been, and remains, a subject of debate. Experiences suggest that success in site conversion from annual grassland "back" to perennial grassland can be expected to be highly variable, subject to site conditions (Keeley, 1993), management, species suitability, and California's considerable inter-annual variations in precipitation events and frequent drought episodes.

Given the Natural Resource Conservation Service's (NRCS) mandate to facilitate conservation efforts on private lands, the agency has a clear interest in engaging this topic. However, it seems probable that at some juncture mitigation credit markets may desire to verify the results of management efforts (US DoE 1999; Follet et al. 2000). Verification methods face technical and economic hurdles, not all of which have been fully resolved.

Natural variation in soil carbon levels over time and distance helps to mask real trends in long-term sequestration, making verification of change in soil carbon pools difficult. Kucharik et al. (2003) reported that variability in C and N pools in soils of Wisconsin CRP lands was sufficiently high to make the detection of less than a 23% change over periods shorter than 10 years unlikely. Smith (2004) produced a model which predicted that, when carbon inputs were modeled to increase by a considerable 20-25%, a

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detection of this with 90% confidence would be possible in less than 10 years *only* if an intensive sampling scheme capable of detecting deviations of ±3% from the initial baseline was used. Conant and Paustian (2002) had more encouraging results, estimating that measurements from 14-28 permanent stations could detect (α=0.10) changes of 2.3 Mg C ha^{-1} in uniform Nebraska grassland soil (Mollisol) micro-plots. These results suggest that, at the present time, even relatively intensive sampling may have difficulty confirming, let alone quantifying, gains in sequestration over periods shorter than a decade. The possibility that this may be overcome exists, but this may be as much related to characteristics of the local environment as to methods. On the basis of present evidence, it seems that validation of sequestration rates in relatively short periods (<10 years) could demand specialized sampling procedures that would strain the technical capabilities of ranch owners/operators, and the costs associated with such validation efforts could be quite high, possibly exceeding the market value of the additional carbon that arid rangelands might be capable of sequestering.

Because little work on methods for monitoring carbon sequestration has been done in annual grasslands so far, and with a view to the potential hurdles that may lie ahead, this field trial was conceived in an attempt to launch investigation of the topic. Our objective was to try out and critique a simple protocol that landowners could use to monitor changes in soil organic carbon resulting from conservation practices implemented on annual rangelands in the foothills of California's Sacramento Valley.

Methods

Site Selection

This field trial was conducted from 2001 through 2004 at two ranches on the west side of the Sacramento Valley, one in Tehama County and one in Yolo County.

Sites were chosen based on their representativeness of soil characteristics, slope, climate, elevation, and the history of use for managed rangelands typical of the area. Because bulk density measurements are problematic in gravelly and rocky soils, sites were restricted to areas with consistent, finer-textured soils. The Tehama County sites were dominated by Myers clay (Mzy). The Yolo County sites were dominated by Sehorn Clay (SkD), Tehama Loam (TaA) and Sehorn-Balcom Complex (SmF_2). A plant species composition survey was conducted for all sampling areas in mid-late summer.

Of the two ranches, one offered one annual range pasture and two fields that, while dominated by annual grasses, principally *Aegilops triuncialis* (13%) and *Lolium multiflorum* (16%), included the perennial grasses *Nassella pulchra* (8%), *Elymus glaucus* (3%), and *Phalaris tuberosa* var. *hirtiglumi* (7%). The other ranch offered a farmed-in field of Perla Koleagrass (*Phalaris tuberosa* var. *hirtiglumis*) established in 1993 in addition to a field recently seeded to Perla, and a field of annual range. These are the six sampling locations referred to below (Loc).

Site Characterization and Sampling

During the spring of the first and third years at least one soil pit was excavated for each soil map unit that comprised >20% of the management unit. Pedons and root masses (depth and architecture) were described for each horizon. Soil samples were taken from 0–5 cm, 5–15 cm, 15-40 cm, and by genetic soil horizon with no layer greater than 25 cm.

Root and soil samples were collected and analyzed for total N, C, lignin, organic matter (OM) and bulk density in the spring of first and third years. To the extent that they could be obtained, the history of management practices applied at each site, including cultivation, irrigation and grazing, were documented.

Soil sampling followed USDA–NRCS Soil Quality Institute (SQI) guidelines for measuring changes in soil organic carbon on grasslands enrolled in the Conservation Reserve Program. The process considers the soil pedon and quantifies root mass at each defined soil horizon (depth segment). Soil and root samples were taken at 0-5 cm, 5-15 cm, and 15-40 cm, and by genetic soil horizon with no layer deeper than 25 cm. Soil samples were analyzed at the University of California, Davis Soil Resource Laboratory for bulk density, total nitrogen, carbon, and organic matter. The bottom 2 cm of each depth segment (0-5 cm, 5-15 cm, etc.) within sample core was used for bulk density determination.

Sampling Design

The Variance Component Analysis uses paired samples to account for micro-scale spatial variability within the immediate sample location. First year samples (A_1, A_2) are randomly selected to account for macro-scale variability related to changing plant density over time within treatments. Paired repeated measure samples for subsequent years ($B_{1...x,}$ $C_{1...x}$ and…. X_n) are collected as close to the permanent markers as possible. Statistic: 2 way ANOVA (variance component analysis) Var. (X) = $\square^2$s/s + $\square^2$é/cs.

Soil/Root Sampling Procedures

1. The minimum number of soil pits needed to establish soil profile characteristics were determined using a Soil Survey with local experience and judgment of NRCS staff. The number of soil/root samples was determined by SQI guidelines (above).
2. Sampling sites were randomly selected; their positions marked, and coordinate locations recorded by GPS (±5 m).
3. Sample cores were extracted in pairs at each site. Soil and root samples were placed in separate plastic bags. Core pairs were taken three inches apart from each other.
4. Step 3 was repeated until all samples were collected.

<u>Analyses</u>

Effects of location, year and depth on total carbon

The dataset was separated into sites sampled in multiple years and the two that were measured only in 2002. Data for the areas measured in multiple years were used to assess the effect of location and time on total carbon content in the different soil horizons.

After several modeling iterations, the mixed model described below was selected to describe the data. Location (Loc), year (Yr), and depth (Depth) were fixed effects in a complete factorial. Point, Year within Point, and Core within Year within Point were random effects. The model was adjusted by restricted maximum likelihood using R.

Analysis of residuals of total carbon (CTot) indicated non-normality. A log transformation almost completely fixed the problem, but 6 observations were identified as outliers because they exceeded the Bonferroni-corrected outlier test at the 0.005 level. This is an extremely conservative level, and the observations were removed from the data.

Further analysis of residuals indicated that there was heterogeneity of residual variance across levels of Depth. Observations near the surface of the soil exhibited greater variance than those for deeper layers. The model formulation was modified into a generalized linear mixed model to accommodate different variances for the different depths.

For the record, the formulation that completely describes the model in R was:

lme.formula(fixed = log(CTot) ~ Loc * Yr * Depth, data = soilData, random = ~1 | Point/Core, weights = varIdent(form = ~1 | Depth)).

"Loc" coded for each of the six sampling sites (locations). "Point" and "Core" identified each point (within site) and core (within point) sampled.

Results and Discussion

The analysis of variance detected significance in all fixed effects and interactions. The effect of depth was by far the dominant one, with year being a distant second.

Table 1. ANOVA of fixed effects and interactions.

	numDF	**denDF**	**F-value**	**p-value**
Loc	5	24	6.9	<0.001
Yr	2	138	40.2	<0.0001
Depth	4	712	1358.3	<0.0001
Loc:Yr	10	138	28.1	<0.0001
Loc:Depth	20	712	7.6	<0.0001
Yr:Depth	8	712	7.3	<0.0001
Loc:Yr:Depth	40	712	6.4	<0.0001

Based on the significance of the fixed effects, confidence intervals were calculated for the mean of each combination of Loc, Yr, and Depth. These 95% confidence intervals are plotted in Figure 1. Two points should be considered in interpreting these results. First, the analyses do not allow statistical inferences about the effects of perennial vs. annual grasses on carbon sequestration because only one of the six sites was dominated by perennial grasses. Second, comparisons of simple differences between locations (Tehama County sites 1-3, and Yolo County sites 1-3), without assigning causality, are valid. Second, at the Tehama County Annual Range site (Figure 2; upper left chart), all depths greater than 5 cm showed more carbon in 2004 than in the earlier years. Upon investigation this was found to have resulted from a sampling/processing error.

Interpretations should be limited to the main and smoother features shown in Figures 1 and 2. Excluding the anomaly described above, the general tendency in this dataset seems to be that there are no differences among locations below 15 cm. These results illustrate the inter-annual variability that occurs in the upper region of the soil profile. This is why it can take a decade or more to establish a directional trend.

The components of variance given by the random effects and their 95% confidence intervals (in standard deviation scale; square the values to get the variances) are given in the following table:

Table 2. Variance Components.

Level:	**lower**	**St. Dev.**	**upper**
Point	0.03785525	0.05952857	0.09361057
Core	0.07770949	0.09269064	0.1105599
Residual	0.1547571	0.1745308	0.1968309
Variance function:			
Depth	**lower**	**mean**	**upper**
A. 0-5 cm	1.2409376	1.4619313	1.7222809
D. 15-40 cm	0.6816232	0.8133337	0.9704948
E. 40-65 cm	0.5775776	0.6938202	0.8334576
F. 65-90 cm	0.5315297	0.643091	0.7780677

The second depth (15-40 cm) was taken as the baseline equal to 1 for the variance function.

All three random components (Point, Year within Point, and Core within Year within Point) exhibited normal distributions. It is therefore valid to use normal and derived distributions to calculate sample sizes and optimal allocation of sampling effort. Because of the heterogeneity of variance across depths, it is necessary to separately calculate sample sizes for the upper and lower sampling depths.

Allocation of sampling resources for estimation of carbon

A critical matter related to establishing baseline soil carbon conditions, and subsequent monitoring, is deciding how many samples to take. The sampling procedure must account for the natural spatial variability in soil carbon levels. Otherwise considerable time and expense can be invested in an effort that fails to detect changes – or mistakes 'natural' variation for real changes in soil carbon levels. The variance components given in Table 2 can be used to guide the design of a sampling protocol using an optimal allocation method. We recommend establishing these variance parameters locally rather than simply using the values provided here, however these can be used as initial estimates until local parameters are known.

'Optimal allocation' refers to the ratio of points (per location [field/pasture]) to cores (sampled per point) to duplicate lab analyses (run per core) [replicate]. Once an optimal ratio is determined, the minimum sample size and cost for a given precision can be calculated. Optimal allocation was done by adapting the procedure described by Sokal & Rohlf (1995, pp. 315-316). The calculations are detailed in Table 3 ("v" = variance of each parameter; "delta" = the desired width of the confidence interval for the mean; "alpha" = the desired level of significance of the test). Ratios of the different sampling components (points, cores, and lab analysis replications) are determined by both the delta value and the component costs that the user provides:

Table 3. Calculation of sample size and optimal allocation.

Top 5 cm							
	vPoint	=StDev^2 =0.05952857^2 = 0.0035	PointPerPast	0	delta	0.15	**<-- Sampling components will be re-calculated as confidence interval width is changed**
	vCore	=StDev^2 =0.09269064^2 = 0.0086	CorePerPoint	0	alpha	0.05	
	vError (within-group SE)	=StDev^2 =0.1745308^2 = 0.0378	RepPerCore	0			
	vMean	0.0018	=vError/(RepPerCore*CorePerPoint*PointPerPast)+vCore/(CorePerPoint*PointPerPast)+vPoint/PointPerPast				
	CostPerPoint	$0	**<-- Component costs will also alter calculation of sampling component number and proportion**				
	CostPerCore	$0					
	CostPerRep	$0					
	CostPerPast	$0	= PointPerPast*CostPerPoint+CorePerPoint*PointPerPast*CostPerCore +RepPerCore*CorePerPoint*PointPerPast*CostPerRep				

To use this optimization scheme, estimates of the variance for points, cores and reps will be needed, sampling costs, and some idea of the likely confidence interval size.

Table 4. Example of Optimal Allocation Run.

Top 5 cm									
	vPoint	0.0035	PointPerPast	5	delta	0.15	**<-- Sampling components will be re-calculated as confidence interval width is changed**		
	vCore	0.0086	CorePerPoint	3	alpha	0.05			
	vError	0.0378	RepPerCore	1					
	vMean	0.0018							
	CostPerPoint	$6.00	**<-- Component costs will also alter calculation of sampling component number and proportion**						
	CostPerCore	$2.00							
	CostPerRep	$9.50							
	CostPerPast	$202.50							

In Table 4 we show an example optimization run using the estimates of variance from the field trial. We estimated the cost distribution among points, cores, and laboratory replications in this example for a single soil layer (upper 5 cm) as follows:

- $9.50 per replication for each analysis (@$7.35), time dividing and preparing core samples, labeling bags, materials costs, etc.
- $6 per point for recording the point coordinate locations, setting a permanent marker for future sampling, organizing the data, preparing sampling procedures, and processing the site-level data
- $2 per core for handling and processing

From these costs and estimates of variance, the optimization routine determined that the least-cost solution to a sampling set that should produce results within the specified confidence interval at the given alpha (probability of detection) would be five points per field, three cores/point and one lab analysis/core, for an estimated cost of $202.50 per field. This reflects the first (establishment) year. Cost per point should be reduced by as much as half ($3, in this case) in subsequent years, as the point establishment work will not need to be repeated. Component variances can be expected to change for different soil types, and for similar soil types exposed to different management, vegetation or environmental conditions.

In our work, no differences between total soil organic matter (OM) and total soil carbon (TC) were detected at any depth among locations, which means that either measurement could be used to predict the other in similar cases. All components exhibited significantly greater variation between 0 and 15 cm than 15 and 90 cm.

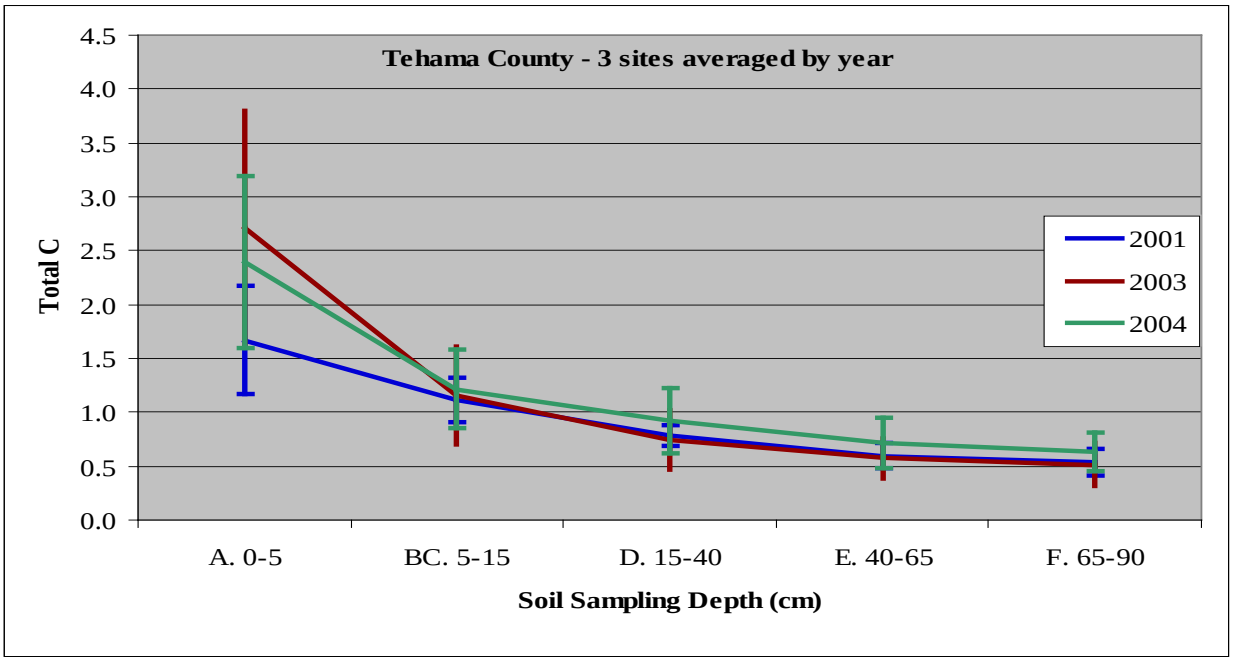
No differences in TC were detected between locations in samples taken *below* 15 cm. However, the TC concentration within the upper 15 cm of the soil profile demonstrated considerable variation. Rates of change in TC concentration from 0 to 5 cm between locations varied by more than 50 percent (Table 5), and rates of change in TC concentration from 5 to15 cm between locations varied by more than 20 percent (Table 6). However, it seems more likely to us that these results were produced by inconsistencies in sampling/handling than by real states of change in carbon pools. This underscores how critically important it can be to minimize all external sources of variation in sampling and processing – and a hint of the technical difficulties that those performing monitoring may face.

Table 5. Between-year rate of change in mean total soil carbon at 0-5 cm between Tehama County fields.

Annual	45%	-78%
Range	40%	-16%
Est. Perla		
New Perla	25%	33%

Table 6. Between-year rate of change in mean total soil carbon at 5-15 cm between Tehama County fields.

Location	2001 -2003	2003-2004
Annual Range	-20%	+51%
Est. Perla	-12%	+8%
New Perla	+26%	-71%



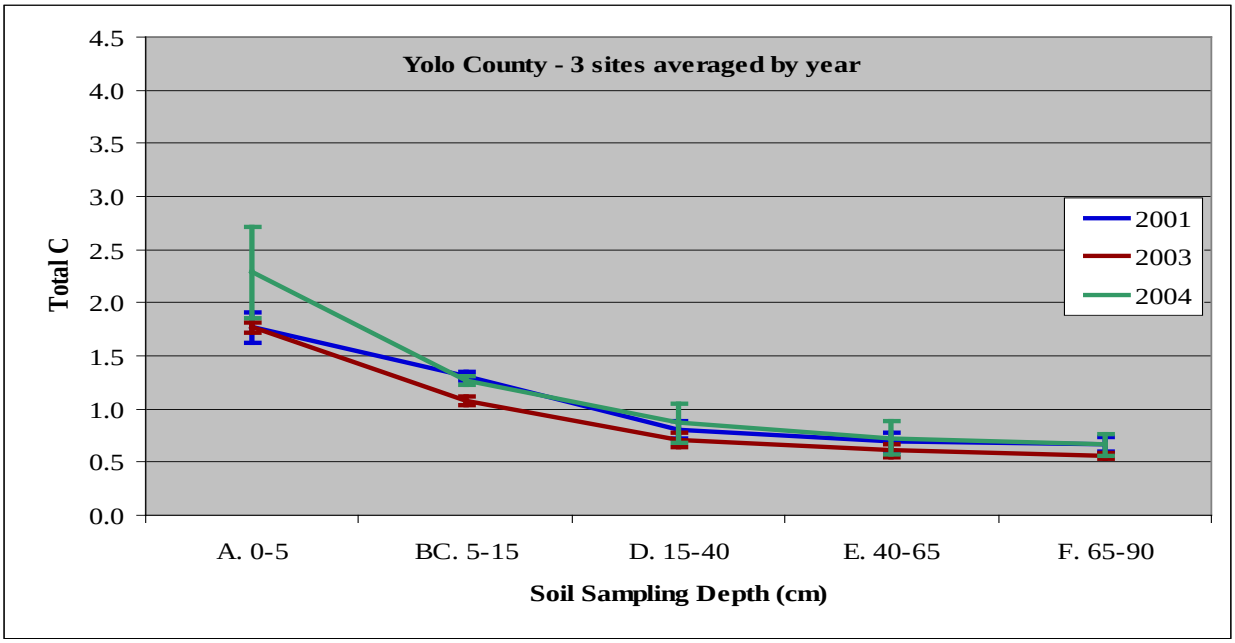


Figure 1. Total soil carbon for Tehama and Yolo County ranches, averaged by year within depth for all locations. Error bars represent 95% confidence intervals.

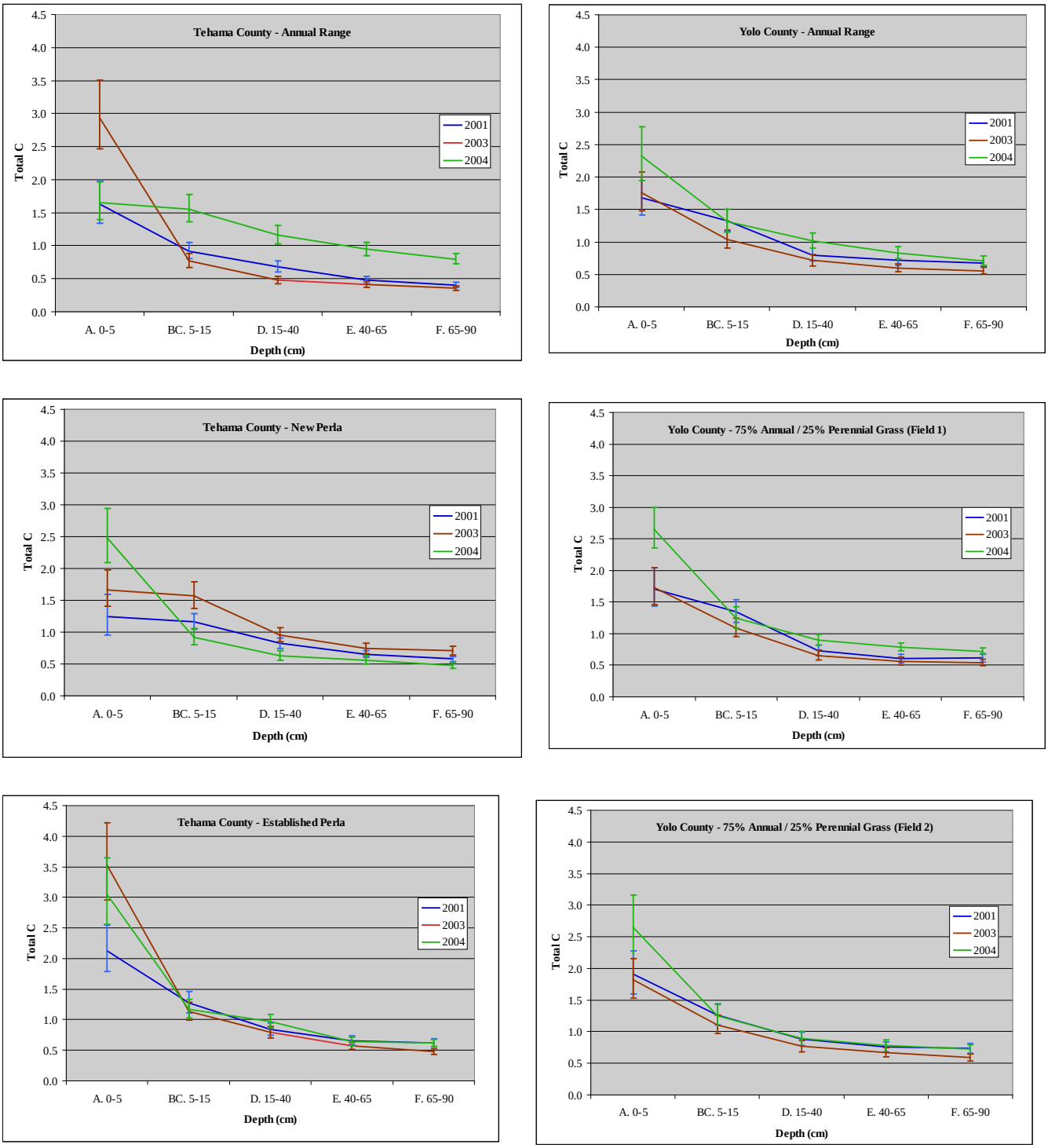


Figure 2. Total carbon by ranch/site over soil depth per year. Error bars represent 95% confidence interval.

Conclusions

Because the magnitude of variation decreases with depth, we recommend calculating sample sizes and distributions separately for samples taken from 0–15 cm and 15–90 cm. Until more datasets providing estimates of variance for sampling components in more California rangeland soils become available, it may be prudent to conduct initial small-scale trials in advance of soil carbon monitoring in order to develop those estimates for localized data sampling. Otherwise there are real risks of investing considerable expense and effort on sites where local spatial and temporal variations in SOC will make detection of changes in trends over time unlikely. Because of the considerable inter-annual variation that we observed, we would advise sampling soil from 0-15 cm every one to three years. While taking baseline values from greater depths would be advised, this trial did not produce any evidence of how long it might take a persistent change to appear at those depths – could one be made. We failed to detect changes at those depths over three years. A procedure like the "Optimal Allocation Tool" described in this article can be helpful for both making decisions about sampling designs, and highlighting the need for more refined data on the variability of soil characteristics.

NRCS staff can expect rangeland managers among their clients to periodically inquire about getting in on carbon credit markets. Because this marketing system is still evolving, NRCS staff should refer interested clients to specialists who are familiar with markets available in the local area, including their rules governing participation. The potential for long-term growth in this market is real, but the magnitude of its growth may depend on the degree to which nations hold and enforce tight regulatory limits on carbon emissions in coming decades (Bell and Drexhage, 2005).

As the science of soil carbon cycling proceeds, estimates of carbon sequestration potential in different ecosystems and under different forms of management are likely to change. In some cases they may be determined to be greater than present estimates, and in others they may be shown to be less. While the revenue generating potential of carbon-credit markets for California annual rangelands is not great at the present time, opportunities for hedging on future growth of these markets are available for those who wish to explore them. The CCX, one of the only markets presently offering offsets for annual rangelands, is not requiring monitoring of trends in actual soil carbon levels, instead using simple verification of the condition of enrolled lands and land management practices. In the future, however, as understanding of soil carbon dynamics improve, and the real potential capacity for sequestration in California rangeland soils, it is possible that monitoring of soil carbon may at some point be encouraged, if not required, at least for ecosystems where wide variations in actual sequestration are possible. It is for those circumstances that the information in this report may be of most value.

Acknowledgements

This effort was funded by the USDA Natural Resources Conservation Service (NRCS) Conservation Field Trial Program, with cost share provided by the California Association of Resource Conservation Districts (CARCD) and USDA Agricultural Research Service (ARS). Principal investigators included Marc Horney, USDA-NRCS Rangeland Management Specialist, Morgan Doran, University of California Cooperative Extension Livestock and Natural Resource Advisor, Emilio Laca, University of California Davis Agricultural Ecologist, Steve Griffith, USDA–ARS Plant Physiologist, Jeff Steiner, Research Agronomist, and Michael Pinner, Soil Biochemist. USDA–NRCS Resource Conservationist Erik Beardsley and Plant Materials Center Manager Dave Dyer coordinated project field operations. Several USDA–ARS technicians, NRCS field conservationists, Yolo County Audubon Society staff, members of the California Chapter of the Soil and Water Conservation Society (CCSWCS), and the California Native Grass Association (CNGA) contribute expertise to the project, as well as assistance with data collection.

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